Technical Report: NAVTRAEQUIPCEN IH-319
AFHRL-TR-80-10

FIELD OF VIEW REQUIREMENTS FOR CARRIER LANDING TRAINING

June 1980

NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA 32813

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BROOKS AIR FORCE BASE, TEXAS 78235

COOPERATIVE STUDY SERIES

Technical Report: NAVTRAEQUIPCEN IH-319/AFHRL-TR-80-10

FIELD OF VIEW REQUIREMENTS FOR CARRIER LANDING TRAINING

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May 1980

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NAVTRAEQUIPCEN IH-319/AFHRL-TR-80-10 — 2. GOVT ACCESSION NO.: AD-A087 012	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Field of View Requirements for Carrier Landing Training.	5. TYPE OF REPORT & PERIOD COVERED: Final
	6. PERFORMING ORG. REPORT NUMBER: NAVTRAEQUIPCEN IH-319/AFHRL-TR-80-10
7. AUTHOR(s): S. C. Collyer, G.L. Ricard, M. Anderson, D. P. Westra, R. A. Perry	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Training Equipment Center, Orlando, Florida 32813	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62205F 63733N 1123-03-50 W1200-PN 0785
11. CONTROLLING OFFICE NAME AND ADDRESS: HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235	12. REPORT DATE: June 1980
	13. NUMBER OF PAGES: 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Operations Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This report documents a cooperative effort by the Air Force Human Resources Laboratory and the Naval Training Equipment Center.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Advanced Simulator for Pilot Training	Simulation
Carrier Landing	Simulator
Field-of-View	Transfer of Training
CIG	Flying Training

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study was conducted to investigate simulator visual field-of-view (FOV) requirements in conjunction with two approaches to training daytime carrier circling approach and landing. The study found that evidence does not support a requirement for a wide-angle visual display for the training of circling approaches and carrier landings.

Three groups of Air Force T-38 instructor pilots were given simulator training in aircraft carrier landings. These pilots were taught to execute

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S/N 0102-014-6601

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) a landing on a simulated aircraft carrier in the Advanced Simulator for Pilot Training (ASPT) at Williams Air Force Base. The visual image for the simulation was provided by a data base which created the aircraft carrier USS Forrestal (CVA-59) in the ASPT computer-image-generation system. The pilots in these three groups were trained under different conditions. Two groups flew a circling approach with one group using a wide (300° horizontal/150° vertical) visual FOV and the other group using a narrow FOV (48° horizontal/36° vertical). A third group flew a straight-in approach using the narrow FOV. A variety of performance measures were taken to characterize the carrier approach. These measures were categorized as (a) instantaneous measures, (b) continuous measures, (c) measures representing the success of the approach at touchdown, and (d) Landing Signal Officer (LSO) ratings. Various statistical routines were carried out with the results obtained from these measures.

Results indicate that, for carrier circling approaches and landings, there are no clear training advantages of a wide-angle visual display. Practice on straight-in approaches, using a narrow-angle visual display, appears to be the most cost-effective use of simulators for training this task.

SUMMARY

Twenty-one Air Force instructor pilots were trained to make daytime carrier approaches and landings using the Advanced Simulator for Pilot Training. All training was conducted by a qualified Navy Landing Signal Officer. Training was accomplished under one of three conditions: Group WC used the simulator's wide-angle visual display (300 degrees horizontal by 150° vertical) and was trained on circling approaches and landings that began at the 180° downwind position; Group NC had a narrow-angle visual display (48° X 36°) but still was trained on the circling task; Group NS also had the restricted field of view and received training exclusively on straight-in approaches and landings. All groups received the same amount of training and were then tested on the circling approach and landing task with the full visual display (identical to the WC training condition).

Large and consistent differences were seen between conditions during training. By the end of training phase, a variety of measures showed that best performance was associated with straight-in training (Group NS) while circling approaches with the narrow-angle display (Group NC) resulted in the lowest scores. However, when all groups were then tested under the WC condition no significant performance differences were found.

It is concluded that evidence does not support a requirement for a wide angle visual display for the training of this task. Providing training on the straight-in portion of the approach with a narrow visual display produced better performance during acquisition, and transfer results that were comparable to those of the other training conditions. In addition, even when instruction was provided on the circling part of the task, the wide field of view produced no clear training advantages. Practice on straight-in approaches, using a narrow-angle visual display, appears to be the most cost-effective use of simulators for training carrier circling approaches and landings.

In view of the implications of this research for simulator design, it is advisable to determine whether the principal results will replicate under conditions of considerably greater training time and with less-skilled pilots as subjects.

PREFACE

The Cooperative Study Series was created for reports of cooperative efforts between the Naval Training Equipment Center and the Air Force Human Resources Laboratory. Those organizations occasionally have pooled their resources for research on flight simulation and flying training techniques. Previous reports have described research on compensation for simulation delays and performance measurement for simulations of air-to-air combat, and the present report is the third of the series. This report describes the results of a study of the field of view necessary for the visual displays of flight trainers designed for the training of circling approaches to landing. In this particular experiment the landing was on an aircraft carrier.

Many people at the Operations Training Division of the Air Force Human Resources Laboratory contributed significantly to this research. At a meeting of the technical advisory group for the Navy's Visual Technology Research Simulator, Mr. Warren E. Richeson, chief of the systems engineering branch, suggested that the Advanced Simulator for Pilot Training (ASPT) would be ideal for this effort, and later, Lt Col Samuel T. Hannan and Capt Ricky A. Perry were assigned responsibility for coordination of the project. They recruited instructor pilots to act as subjects and attended to innumerable details during the months of preparation prior to the collection of data.

During this period of preparation Capt. Edmund Chun and Mrs. Michelle Bliss (of Singer-Link) attended to the definition of experimental conditions and the measurement of flying performance. Mr. Jim McHugh, Mr. Scott Wall, and Mr. Robert Rife, all of Systems Engineering Laboratories, performed much of the work necessary to define the image of the aircraft carrier and develop a model of the operation of the Fresnel Lens Optical Landing System. Mr. Donald Bustell of Singer-Link helped to verify their adequacy, and Mr. William Brubaker developed the video taped materials used for briefings.

During the collection of data, Mr. Thomas Farnan acted as operations coordinator and Mr. Donald Fulton, Mrs. Pamela Kosirog, and Mr. Mark Kilgore, all of Singer-Link, acted as operators at the advanced instructor's console of the ASPT. From the initial planning of the experiment through the report preparation, Mr. Robert Woodruff and Dr. Harold Warner (of the University of Dayton) provided much useful support and advice.

Several Navy personnel were also helpful. As usual, Capt William C. Mercer, the Chief of Naval Education and Training Liaison Officer at Williams Air Force Base provided encouragement, attended to numerous details, and was a great help to the entire effort from start to finish. LCdr Wayne Kelly and Lt James Brodengeyer acted as liaisons between COMLATWING ONE, NAS Cecil Field and the Naval Training Equipment Center. They were instrumental in providing Lt Anderson so that an operational Landing Signal Officer could conduct the training.

Finally, Dr. Gavan Lintern of Canyon Research Group provided many suggestions concerning the design of the study and the resulting analysis of the data.

No experiment can be accomplished without subjects willing to perform under its various conditions, and we would like to thank the volunteer pilots of the 97th Flying Training Squadron for taking the time to participate: Capt Randolph Albright, Capt Steve Allen, Capt David Barker, Lt Charles Glauser, Lt Scott Hammond, Capt Steven Hardaway, Lt Julius Hargrove, Capt Dan Hulsey, Capt Mark Johnson, Lt Richard Kleinhans, Capt R.B. Melhorn, Capt Marlo Mellum, Capt Bruce Myers, Capt David Parker, Capt Dennis Pike, Capt George Pinkston, Capt Kim Ritchie, Capt Gregory Smith, Lt Jon Turner, Lt Robert Walden, and Capt Thomas Watson.

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INTRODUCTION

BACKGROUND

Visual simulation technology continues to be a critical issue for the flight training research community. The perceptual requirements that simulators must satisfy, and the visual information that is critical for optimum pilot training are still very much in question. With the continued pressure for increased realism in visual simulation, and with the increased costs associated with this realism, the potential training payoff of visual technology improvements must be clearly understood.

A point that is sometimes overlooked in discussions of simulation fidelity research is that it can be misleading to investigate simulator variables apart from training variables. Rather, the nature of the training system should be considered in its entirety. Failure to look at training techniques and training technology together may be the result of regarding simulators simply as substitutes for the aircraft. This point of view easily leads to the idea that training in the simulator should be accomplished in the same way as training in the aircraft. This concept, in turn, suggests the need for a great deal of realism (i.e., if the simulator is substituting for the airplane, then the simulated environment should substitute for the real world). In fact, when simulator training is almost identical to aircraft training, a strong case can be made for high realism.

Some researchers, however, are suggesting that simulator-based training should sometimes be conducted in a very different way from that which is possible in the airplane (Hughes, 1979). When such a possibility is seriously considered, departures from real world fidelity in the visual scene may seem less heretical.

The present study concerns both a training variable and a visual fidelity variable. A task is considered which, if it were taught in the same manner as it is taught in the aircraft, might require a costly approach to visual simulation. The following questions are being asked. How effective is the alternate method of training, which would permit the use of a less costly visual system? How effective would the original approach to training be if the less costly visual system were used?

The visual fidelity parameter of interest in this study is the field of view (FOV), which has perhaps the greatest cost implications of any simulator design variable. For equivalent levels of resolution and scene detail, a wide angle visual system is many times the cost of a typical single-window (approximately 48° x 36°) display system. For some tasks, such as air combat training, the added cost can be easily justified by the improved training capability of the simulator. For some other tasks, the value of having a wide visual coverage should be carefully examined.

FIELD OF VIEW RESEARCH

Considerable research into the effects of FOV restriction on pilot performance has been performed over the years, for both fixed and rotary wing aircraft. In the case of fixed-wing aircraft, there has been a number of in-flight studies demonstrating relatively little loss of flying skill, even when the FOV is considerably less than that provided by even the narrow angle visual systems of current simulators. Some of the earliest work was done by Roscoe (1948, 1951). He found that takeoffs and landings could be accomplished safely by experienced pilots with a FOV as small as 10° horizontal x 10° vertical, although increasing the FOV did improve precision. Flight trials conducted by Armstrong (1970) under day and night conditions with good and poor visibility showed virtually no decrement of landing performance when the horizontal FOV was restricted to 49°. Reeder and Kolnick (1964) found both takeoff and landing performance to be adequate when pilots looked at closed-circuit TV pictures in which the FOV was 21.5° horizontal and vertical. Perry, Dana and Bacon (1967) looked at 180° approaches and landings in a T-33A jet and found that, even with a FOV as small as 5.7° horizontal x 30° vertical, touchdown performance was not degraded. Interestingly, pilots believed that even slight FOV restrictions were detrimental to their performance. This point raises the possibility that more sensitive measures of performance may have revealed a larger effect in some of these studies. Nevertheless, the fact remains that performance remained within the safe and acceptable range even with substantial FOV restrictions.

Simulator studies on the Air Force Advanced Simulator for Pilot Training (ASPT) have also examined the FOV variable and have measured performance more precisely than is usually possible with in-flight studies. Irish, Grunzke, Gray and Waters (1977) looked at pilots' ability to perform five maneuvers in the ASPT under combinations of six independent variables, including FOV. Only one maneuver, an aileron roll, was performed significantly better with a wide FOV (300° horizontal x 150° vertical) as compared to a 48° x 36° window. The other maneuvers showed minor improvement favoring the wide FOV. A later study (Irish and Buckland, 1978) again looked at pilot performance for the same five maneuvers and included a third, intermediate FOV level (144° horizontal x 36° vertical). The results were complex and large differences were seen between pilots, but in general the large FOV was best for the aileron roll, the barrel roll and the 360° overhead pattern. Measures sensitive to roll performance were most likely to reflect FOV differences.

The studies reviewed to this point have concerned tasks such as landing and basic contact maneuvers which, for fixed wing aircraft, typically require the pilot to look more or less straight ahead. Restricting the FOV then results primarily in a loss of peripheral information, and this loss generally has only a small effect on performance. A task requiring pilots to use their central, rather than peripheral, vision over a large area was shown to be much more sensitive to FOV variations. Woodruff, Longridge, Irish and Jeffreys (1979) looked at aerial refueling in the ASPT, a task that required the pilot to attend to small size and shape changes in the tanker aircraft. The authors found FOV to be an important variable affecting performance of this task. A consistent result was that performance was best with the full ASPT FOV (300° horizontal x 150° vertical).

Most studies that have looked at the effects of restricting central (foveal) vision have been concerned with helicopter or V/STOL (Vertical/Short Takeoff and Landing) aircraft. For example, Stapelford, Clement, Heffley and Booth (1979) looked at pilots' ability to land a simulated V/STOL aircraft on a destroyer. Although FOV was not a variable, numerous pilot comments indicated that the 48° horizontal x 36° vertical FOV was inadequate for judging fore-aft position and velocity over the deck, and for distinguishing between deck motion and aircraft motion. NAVAIRTESTCEN (1978a) describes the evaluation of the SH-2F (LAMPS MK I) Weapons System Trainer in which inadequacies ascribed in part to a limited vertical look-down angle have restricted its usefulness for training helicopter shipboard landings. Other studies concerned with FOV issues for helicopter flight (Yeend and Carico, 1978; NAVAIRTESTCEN, 1978b; Frezell, Hofmann and Oliver 1973) have also indicated the desirability of a relatively large FOV, particularly for hover and landing tasks. Thus, although there is a scarcity of controlled objective experiments looking at FOV requirements for helicopter and V/STOL aircraft, there is considerable support (based on pilot opinions) for the assertion that a relatively large FOV is desirable when operating these aircraft at slow speeds and close to obstructions. In these situations, the pilot must use his central vision, scanning the environment to check for obstructions and to judge his distance to nearby objects.

All studies discussed so far have dealt with how FOV affects pilots' ability to fly, and not how well they can learn to fly. However, a recent study by Nataupsky, Waag, Weyer, McFadden and McDowell (1979) did examine the effects of restrictions to the

FOV on transfer of training. The variables in this experiment, conducted on the ASPT, were platform motion (6 degrees of freedom versus no motion) and FOV ($300^{\circ} \times 150^{\circ}$ versus $48^{\circ} \times 36^{\circ}$). Students were trained on four tasks: takeoff, steep turn, slow flight, and straight-in approach and landing. Following training in the simulator, they were tested during their first sortie in the T-37 aircraft. The results for the in-simulater training phase showed some motion effects, and two significant main effects for FOV (for two tasks, elevator control movement was greater in the narrow FOV condition). Subsequent performance in the aircraft revealed no significant FOV effects. Thus there is no evidence to suggest that training with a wide FOV improved transfer of training to the aircraft for the four basic contact maneuvers studied.

CARRIER LANDING TRAINING

This experiment concerns training a typical Navy daytime carrier approach and landing, starting from the 180° downwind position. The task, described in detail in the next section, involves two main components: (a) a left-hand descending turn that begins opposite the stern of the carrier and continues until the aircraft rolls out on the final approach, approximately 3/4 mile from the ship and (b) a final straight-in descent terminating with an arrested landing. Pilots typically fly the turn using instruments predominantly, supported by occasional glances at the ship in order to judge the progress of the turn and to ensure that the roll-out is completed when the aircraft is in line with the landing deck.

One question being asked in this experiment was the following. If a simulator is being used to help train this task should available simulator flight time be concentrated on the final straight-in portion of the task, or should considerable practice also be given on the turn? The argument for training only on the straight-in approach notes that this portion of the task is the most demanding, and requires the most practice in order to learn the techniques of a precise, controlled, on-speed descent. Training on the turn is less important, particularly since pilots have already become proficient at making turns before carrier training begins. The other viewpoint, however, stresses the importance of being in precisely the correct position when the straight-in approach begins, and suggests that the final approach should be considered as starting at the 180° position. If pilots cannot complete the turn with precision, their chances of landing successfully are greatly reduced; therefore, simulator practice on this portion of the task should not be neglected.

While the above issue is of interest to those who design training programs, it is actually of greater importance to those who specify the requirements for flight simulators, as well as to those who allocate funds for their purchase. This is because of the implications for the simulator FOV. If practice in the simulator is restricted to straight-in approaches, the evidence suggests that a relatively narrow FOV should suffice, since only peripheral information is being removed. If, however, it is better to begin training at the 180^{o} position, a narrow FOV may be a serious detriment to training. Since the carrier would not be in view during the turn, important centrally-acquired (foveal) information has been removed that could affect the student's ability to learn the task.

STUDY OBJECTIVE

To summarize, the objective of this study was to investigate simulator FOV requirements in conjunction with two methods for training the daytime carrier circling approach and landing task. This was accomplished by training some pilots on circling approaches with either a wide or narrow FOV and training others on straight-in approaches with a narrow FOV. All were then tested on the circling task with the wide FOV.

SECTION II

METHOD

SUBJECTS

The 21 volunteers who served as subjects in this experiment were Air Force instructor pilots from the 97th Flying Training Squadron located at Williams Air Force Base, Arizona. All were instructors for advanced jet training in the T-38 aircraft. As a group, they had accumulated between 705 and 1450 individual hours of flying with a group average of 1038 hours.

EQUIPMENT

This study used the Advanced Simulator for Pilot Training (ASPT), a research device located at Williams Air Force Base. Numerous papers have described this facility; a good overview is given by Gum, Albery, and Basinger (1975). Each of two simulator cockpits is surrounded by a mosaic of seven pentagon-shaped CRT channels to display a 300° horizontal x 150° vertical field of view with the optics to present computer-generated visual scenes as virtual images. Each cockpit is mounted on a motion platform and each is equipped with a G-seat. An instructor's console contains repeater instruments as well as CRT displays to indicate the state of the simulated aircraft along with TV monitors for the CIG channels. The console also contains keyboards and switches to determine conditions of the experiment and to initiate individual trials. Data collected during trials can be stored until the end of a testing session and then recorded on a variety of permanent media. At the time of this study, the cockpits and instructor's console were controlled by two Systems Engineering Laboratories model 86 computers.

The configuration of the ASPT cockpits can be changed, and for this study the "B" cockpit was configured as an A-10. This is a single-seat attack aircraft similar to those used for carrier operations. To allow the subjects to fly a constant angle-of-attack (AOA) approach, an AOA indexer was installed in the appropriate position in the A-10 cockpit, and a repeater indexer was mounted on the instructor's console. Because the interest of this study was the field of view needed to train carrier approaches, neither the motion platform nor the G-seat was active. Several graphics displays and TV monitors were available on the console, and one of these was used to display the CIG channel directly in front of the pilot. A graphics tube also was used for a Carrier Controlled Approach (CCA) type of landing display. The Landing Signal Officer (LSO) who conducted training from the console had the pilot's straight-ahead visual scene, the AOA indexer, and other indicators (such as for power setting, aircraft altitude and airspeed) located in a restricted area which he could monitor.

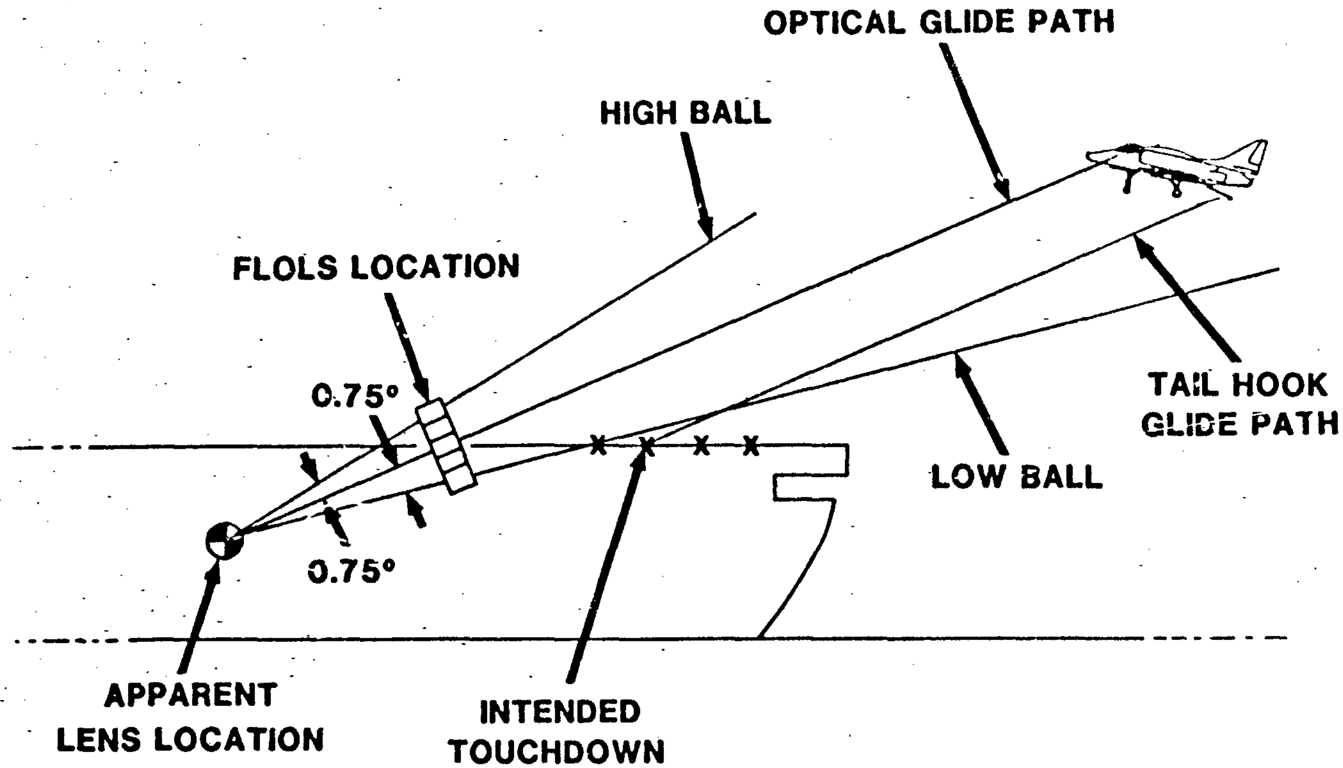

Figure 1. Carrier Glideslope Geometry.

TASK AND EXPERIMENTAL CONDITIONS

The experimental tasks were simplifications of day and night carrier approaches. During the day, aircraft are normally recovered by having them fly abeam of the starboard side of a carrier in the direction of the ship's heading. A specified time after passing the ship, the pilot executes a 180° turn to the left and flys back past the approaching carrier about 1 to 1.5 miles to its left. When the aircraft passes the carrier's ramp (the aft end of the landing deck), a 190.5° turn to the left is performed so that when the pilot rolls out, the aircraft is in line with the center marking of the recovery deck. At night the aircraft arrives in a marshalling area about 10 miles aft of the ship and then flies a straight-in approach.

Final approach descent is guided by the Fresnel Lens Optical Landing System (FLOLS) which displays a vertically moveable center light beam (the "meatball") which must be kept aligned with rows of stationary horizontal lights. When the aircraft is above or below the correct glideslope, the meatball is seen as above or below the horizontal reference lights. If the pilot is viewing a centered meatball, and if the aircraft has the correct AOA, the tailhook will be in the proper position to catch one of the arresting wires on the deck. These relations are depicted in Figure 1. For this experiment the desired glideslope was 3.5°.

The FLOLS beam is about 45° wide so that when the aircraft is about four-fifths through the turn, the meatball can be seen and glideslope adjustments can be started. Except for occasional glances to locate the aircraft carrier, the circling approach is made on instruments until the meatball is sighted. Then pilot actions should be determined by two sources of visual cues: (a) information on glideslope and lineup presented by the FLOLS and markings on the carrier deck, respectively; and (b) AOA information by the indexer inside the cockpit. For either day or night approaches, pilots make a constant airspeed approach by manipulation of the throttle and stick while lineup is maintained by control of the stick and rudder. Since the optimum AOA is maintained until touchdown, the aircraft is not flared at landing.

The visual image for the simulation of this task was provided by a data base for the aircraft carrier USS Forrestal (CVA-59) for display by the ASPT Computer Image Generation (CIG) system. This system has the capability for one moving model which was devoted to the FLOLS display. The result was that the carrier was stationary against a sea/sky horizon, and to compensate for this, 30 knots of wind was created from a heading of 349.5° (down the flight deck). To allow movement of the meatball, ± 2 ball-widths plus a centered position were divided into 15 positions. Each "ball" unit thus had 3 positions allotted to it, so that ball movement would be fairly smooth. As the ASPT CIG system is a monochrome display, the 3 lowest positions were flashed to represent the change to a flashing red ball at 2-balls low. Waveoff lights were also flashed when the LSO decided the aircraft was not in a position to land safely.

Because of limits on the resolution available with the ASPT CIG system, the size of the FLOLS display was enlarged when at a range greater than 3/4 mile. At the 3/4 mile point, this size was reduced and the display moved in closer to the ship; at the 1/4 mile point, the FLOLS was its normal size and in its normal location. A last point should be noted about the carrier image. To enable pilots to exit the final turn lined up with the center line, the carrier's wake was made to disperse at an angle of 21°. The right edge of the wake was then parallel to the flight deck and a little to the right of the centerline. These features can be seen in Figure 2, which is a photograph taken when the simulated aircraft was approximately 1/4 mile from the carrier.

Two starting positions and two FOVs were used to create the three conditions for training. A circling approach was started at the point marked C in Figure 3. This point was 1000 feet ahead of the carrier, 1.15 miles abeam. The aircraft was started at an altitude of 600 feet and an airspeed of 120 knots. Straight-in approaches started with the aircraft at point S in Figure 3. So that pilots learning under this condition would have to manipulate the controls to become lined up, point S was displaced to the left of a heading straight down the carrier deck. This point, chosen so that the circling and straight-in approaches involved the same flight time (about 130 seconds), was 2.3 miles behind the carrier and 1.1 miles to the left of centerline.

Two fields of view were used. A wide FOV condition represented the limits available on the ASPT (300° horizontal x 150° vertical), while a narrow FOV was set to the 48° horizontal x 36° vertical dimensions that are characteristic of many training simulators. Because the carrier was lower than the aircraft and the approaches were flown with a high AOA, this window was positioned to be 6° above the horizon and 30° below it. This location permitted more of the carrier and its wake to be displayed.

All training in this experiment was conducted by an operationally qualified Landing Signal Officer (LSO). LSOs are Naval aviators whose duties include communicating with pilots on every carrier approach that is made, in order to ensure a safe approach. They are also responsible for conducting all carrier qualification training. At the time of the study the LSO was assigned to a Readiness Training Squadron (VA-174) at NAS Cecil Field, Florida.

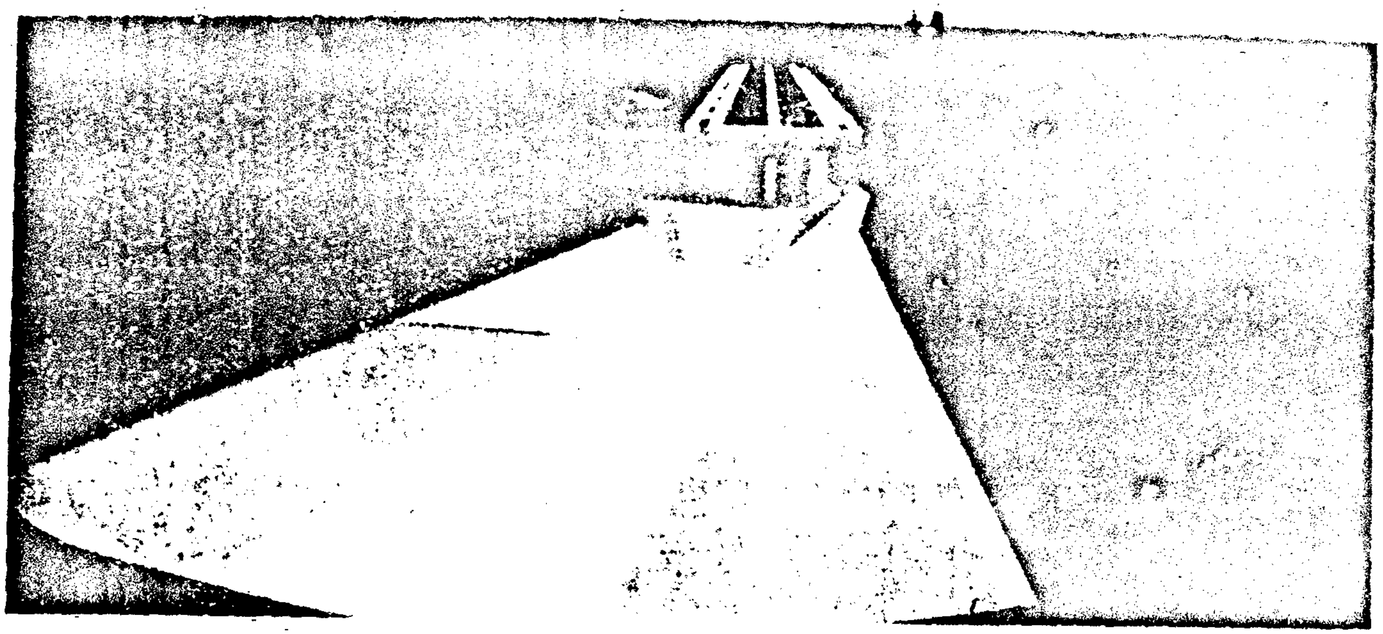

Figure 2. CIG Carrier at Range of Approximately ¼ Mile.

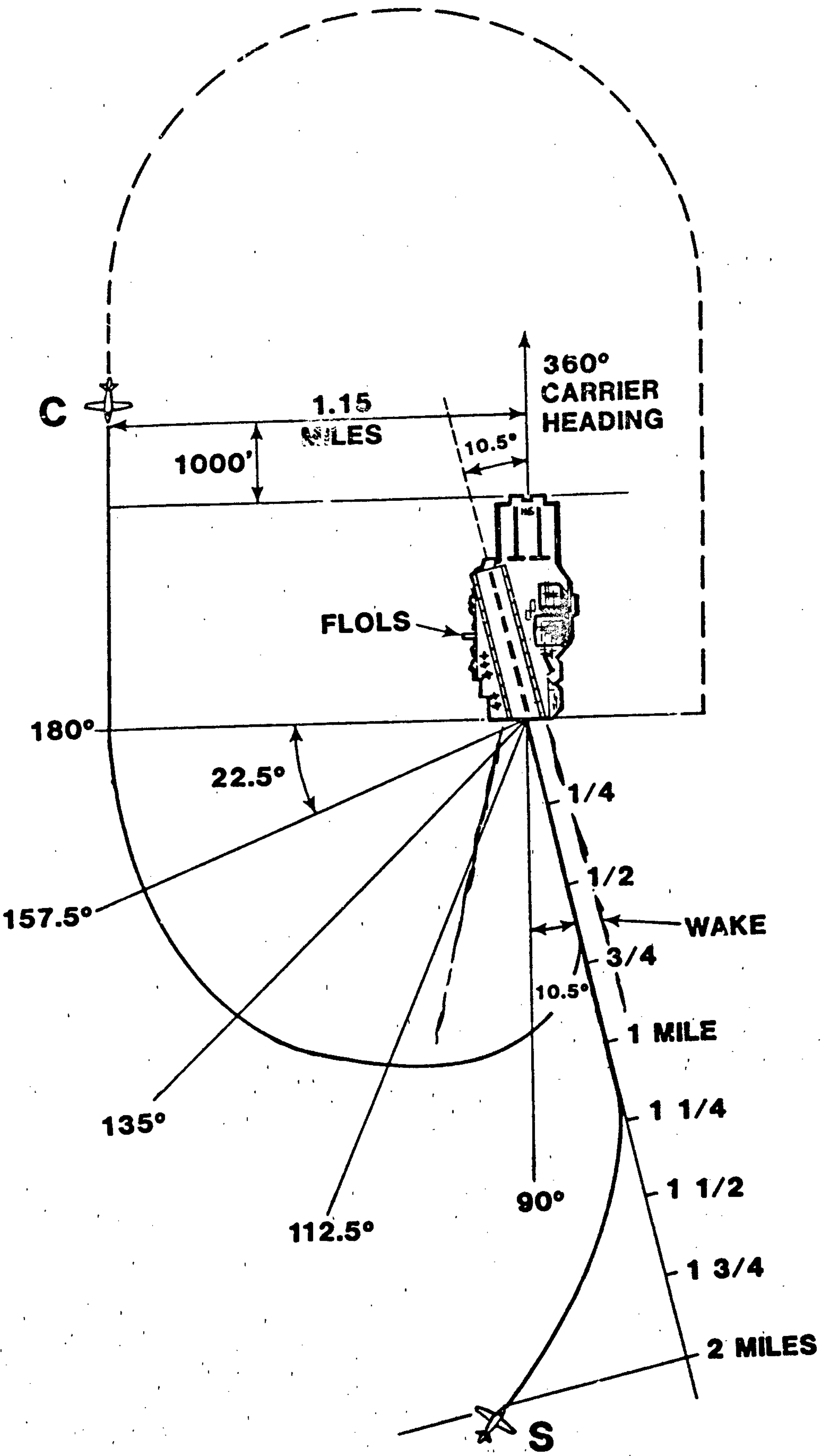

Figure 3. Carrier Overhead Approach Geometry (not drawn to scale).

DESIGN

This study was designed as a transfer experiment where both the acquisition and transfer phases occur in the same device. This "quasi" transfer design evaluates acquisition under various conditions by testing with the same device used for training. The two FOVs and two approaches previously described were combined to form three conditions for acquisition, as shown in Table 1. A wide FOV, circling approach (WC) condition was used to

TABLE 1. SUMMARY OF EXPERIMENTAL CONDITIONS

TRAIN			TEST	
Group	FOV	Approach	FOV	Approach
WC	Wide	Circling	Wide	Circling
NC	Narrow	Circling	Wide	Circling
NS	Narrow	Straight	Wide	Circling

represent carrier approach training that could be accomplished with a device equipped with a wide-angle visual display. A narrow FOV, circling approach (NC) condition represented training in which current narrow angle displays could be used to teach the last turn as well as final approach phases of aircraft recovery, and a narrow FOV, straight-in approach (NS) condition represented training as currently conducted with narrow-angle CIG visual displays. Acquisition under these conditions was assessed by using a transfer condition that represented the highest fidelity available on the ASPT - a wide FOV and a circling approach (the WC condition).

Six T-37 instructor pilots assigned to the Air Force Human Resources Laboratory (AFHRL) served in some preliminary tests to determine the rates of acquisition under these conditions. On the basis of those tests, we decided to allow 15 acquisition trials per condition followed by 15 trials on the WC transfer condition.

PERFORMANCE MEASUREMENT

A variety of measures was taken to characterize the carrier approach. Some of these we believed would be sensitive to the conditions of acquisition which were investigated and some were used to create a framework for further experiments on carrier landing. The measures fall into four categories. First are instantaneous measures taken at specific points along the turn and final approach. Starting when the aircraft passed the 180° radial, the AOA, altitude, X and Y position, and bank angle were recorded every 22.5° until the aircraft passed the 90° radial. Then, when the aircraft was past the 90° radial and was less than one mile from the ramp, glidepath deviation, centerline deviation, and AOA were sampled every 1/4 mile until the aircraft passed the ramp. For the straight-in approaches, this measurement started as the aircraft passed the one-mile position and then proceeded normally.

Second, continuous measures were also recorded. Two sets of these were taken and both were sampled at 15 per second. The first of these sets represented a variety of pilot control inputs to the aircraft that were measured over 1/4-mile segments starting at the one-mile marker and ending at the ramp. A second set of continuous measures was taken over the flight from the 1/2-mile point to the ramp. These were the mean and rms deviation; the percent of the time a parameter was in a high, correct, or low category; and the maximum and minimum deviations of glideslope error, centerline deviation, and AOA. The criteria used to determine in which category (high, on, or low) a given observation occurred are presented in Table 2. As all of the approaches were close to the glideslope by the 1/2 mile marker, these represented system measures of the accuracy of control for the various conditions.

TABLE 2. TOLERANCES FOR TIME-WITHIN-TOLERANCE MEASURES.

	Glideslope	Lineup	Angle of Attack
High	>+1.0 ball (>3.875°)	>+1.5° (right of centerline)	>22 units
On	±1.0 ball (3.5±0.375°)	± 1.5° (centerline)	20-22 units
Low	<-1.0 ball (<3.125°)	<-1.5° (left of centerline)	<20 units

Third, several measures were taken which represent final states of the aircraft and the success of the approach at touchdown. At the ramp, the centerline deviation and the hook-to-deck distance were measured; measures at touchdown included the bank angle, pitch angle, the vertical velocity, and the wire caught. If no wire was caught, the flight was classified as a bolter (touchdown beyond wires), ramp strike (impact with aft end of landing deck), or waveoff.

Fourth, two ratings were made on each approach. One of these was made by the LSO using an expanded scale of LSO ratings. This scale translated the "cut", "waveoff", "no grade", "fair", and "OK" judgments onto a 0-12 scale as shown on Table 3. The other rating was the landing performance score (LSP) developed by Brictson, Burger and Wulfeck (1973). The LPS scale, ranging from 1-6, assigns scores to waveoffs, bolters, and traps. This scale is described in Table 4.

TABLE 3. NORMAL LSO GRADING CRITERIA IN RELATION TO THE EXPANDED SCALE USED IN THIS EXPERIMENT

Modified Scale		Normal Scale	Common Terminology		Description
12 11 10	←	4	"OK"	→	Minor deviations and above average corrections
9 8 7	←	3	"Fair"	→	Average deviations and corrections
6 5 4	←	2	"No Grade"	→	Major deviations and below average corrections
3 2 1	←	1	"Waveoff"	→	Not in position to land safely
0	←	0	"Cut"	→	Unsafe approach (rarely given)

TABLE 4. LPS ASSIGNED TO VARIOUS LANDING OUTCOMES (ADAPTED FROM BRICTSON, ET AL., 1973).

Landing Outcome	Landing Performance Score (LPS)
Waveoff	1.0
#1 Wire	3.5
#2 Wire	5.0
#3 Wire	6.0
#4 Wire	4.5
Bolter (touchdown beyond wires)	2.0
Ramp Strike (impact with ship)	0[a]

[a] Not part of original scale developed by Brictson et al.

PROCEDURE

A considerable amount of development work was necessary for this experiment. A data base for the image of the USS Forrestal (CVA-59) for the CIG system of the ASPT existed but had to be adjusted for the correct geometry for an A-10 making a carrier approach. Most of these changes reflect simulation of the FLOLS which has been discussed by Golovcsenko (1976). Also, several options were open for the design of the experiment and preliminary data had to be collected for these various decisions. The LSO decided that the duration of his briefing could be reduced if sections of Navy training films were used; consequently two films (one on carrier landing and one on the operation of the FLOLS) were edited to make a short video tape for using during his briefing.

The T-38 instructor pilots were not familiar with the ASPT, so to acquaint them with control of that device two sets of initial conditions for familiarization flights were created. In an initial instrument flight the pilot started at an altitude of 2000 feet, and then executed a 30° angle-of-bank turn to the right until a change of heading of 60° was made. Then he returned to the original heading, still holding the optimum AOA. He then descended at 500 fpm to 1000 feet and leveled the craft for 10 seconds. Last, a left turn at 30° of bank was performed. All this took about 5 1/2 minutes and was designed to provide practice on aircraft control while holding AOA constant. A second set of flights was created to illustrate acceptable carrier approach performance for each of the three experimental conditions. These were flown by the LSO, recorded, and later used as demonstration rides before the first attempt by each subject to perform the task.

Subjects were assigned to the conditions of acquisition on the basis of total flight hours and hours of T-38 flight. During the course of the data collection, some changes to these assignments had to be made, but these did not alter the composition of the groups. The results of the matching, as well as the flight hours and number of landings within the 30 days previous to the experiment, are presented in Table 5. None of these measures indicates differences between the groups.

TABLE 5. FLIGHT EXPERIENCE OF PILOTS IN THE THREE TRAINING GROUPS.

	Group					
	WC		NC		NS	
Measure	Mean	S.D.	Mean	S.D.	Mean	S.D.
Overall						
Total flt. hrs.	1013	211	1052	178	1049	254
T-38 hours	799	216	923	160	916	200
Prev. 30 Days						
Total hours	25	16.5	25	10.6	26	7.9
No. landings	13	9.5	27	20.1	20	12.9

Three 3-hour testing sessions were scheduled each day with a different pilot assigned to each. This time allowed for a briefing, an acquisition period, and a transfer or testing period. The pilot was first presented the video-taped material on carrier operations, and then received two briefings. The first of these was a mandatory safety briefing on the operation of the cab and fire control equipment on the ASPT. The second was a description by the LSO of the carrier approach task and the techniques of control for flying a constant AOA descent, followed by a description of the operations of the FLOLS. Pilots were reminded that small changes of pitch and power were used to remain on the glideslope, and that the primary cues for glideslope and lineup control were the FLOLS and deck markings. The LSO also provided nominal values for aircraft parameters at various positions about the turn. For instance, they were told to be at an altitude of 600 feet at 180°, 450 feet at 90°, and 375 feet at lineup, and to hold approximately 22° angle of bank and 21 units AOA during the turn. LSO calls were explained so that the pilot knew that some calls about power settings, aircraft altitude, and waveoff were mandatory and required a response and that other calls such as "you're high" or "check line-up" were informative. Pilots were also reminded not to flare and to go to military power at touchdown. The general purpose of the experiment was then briefly described to them.

After a pilot was seated in the A-10 cockpit, he first flew the familiarization flights previously described. He then viewed the demonstration flight appropriate to his particular acquisition condition. At this point a block of 15 trials was started. These trials, including the 130-second flight time, took about 3-4 minutes each so that the entire data collection for each pilot, including his briefing, took about 2.5 hours. After the 15 acquisition trials, each pilot was given a 10-15 minute rest outside of the cockpit, and then returned for the WC demonstration flight and 15 transfer trials. At the end of testing, the pilots were briefed about their performance.

During each trial, the LSO, seated at the instructor's console, provided mandatory and informative calls to the pilots. After each trial he briefed the pilots concerning their approach performance, and provided additional instruction as required.

All the recorded measures were stored in a data file in core until the end of a day's testing. They were then transferred to a disk memory and a hard copy was made. When the experiment was finished, these data were copied to magnetic tape and returned to the Naval Training Equipment Center for analysis.

SECTION III

RESULTS

Results are presented separately for three major segments of the task: touchdown, final approach, and the turn beginning from the downwind, abeam position.

TOUCHDOWN PERFORMANCE

The LPS

Touchdown scores are summarized in terms of the Landing Performance Score (LPS) developed by Brictson et al. (1973). This measure, which basically reflects longitudinal touchdown position, was developed as a readily-obtainable summary measure of carrier landing performance. It has been found to be sensitive to different types of aircraft and to day versus night approaches in a large number of fleet landings, and correlates well with LSO ratings of final approaches and landings (Brictson et al., 1973). Table 4 presents the LPS assigned to various possible outcomes.

Figure 4 presents the LPS data for the three groups, for both the training and the test trials. To improve the clarity of visual presentation, scores are averaged over three successive trials.

Analyses of variance (ANOVAs) were performed separately for the training and the test phases. (Appendix A contains summary ANOVA tables for measures discussed in this section). In the training phase, there was a significant difference between training conditions ($p<.05$) and a significant effect of trials ($p<.005$). During the test phase, however, when all groups performed the circling task with the wide FOV, there were no significant effects.

Thus, for this measure of touchdown performance, all groups showed substantial improvement across the 15 training trials. Furthermore, performance was clearly superior for the group that flew straight-in approaches (Group NS), and was poorest for the students flying circling approaches with the narrow FOV (Group NC). Across the 15 test trials no further learning was reflected by this measure, and there was no evidence that the training conditions had any differential effect on subsequent transfer performance.

Table 6 summarizes the landing results in terms of the four categories of outcome: traps (successful wire catches), wave-offs, bolters (touchdowns beyond the wires), and ramp strikes (impacts with the stern of the ship). It may be seen that the most probable outcome of a training trial was a waveoff, and that the overall boarding rate (percentage of traps) during training was 28% and during testing was 47%.

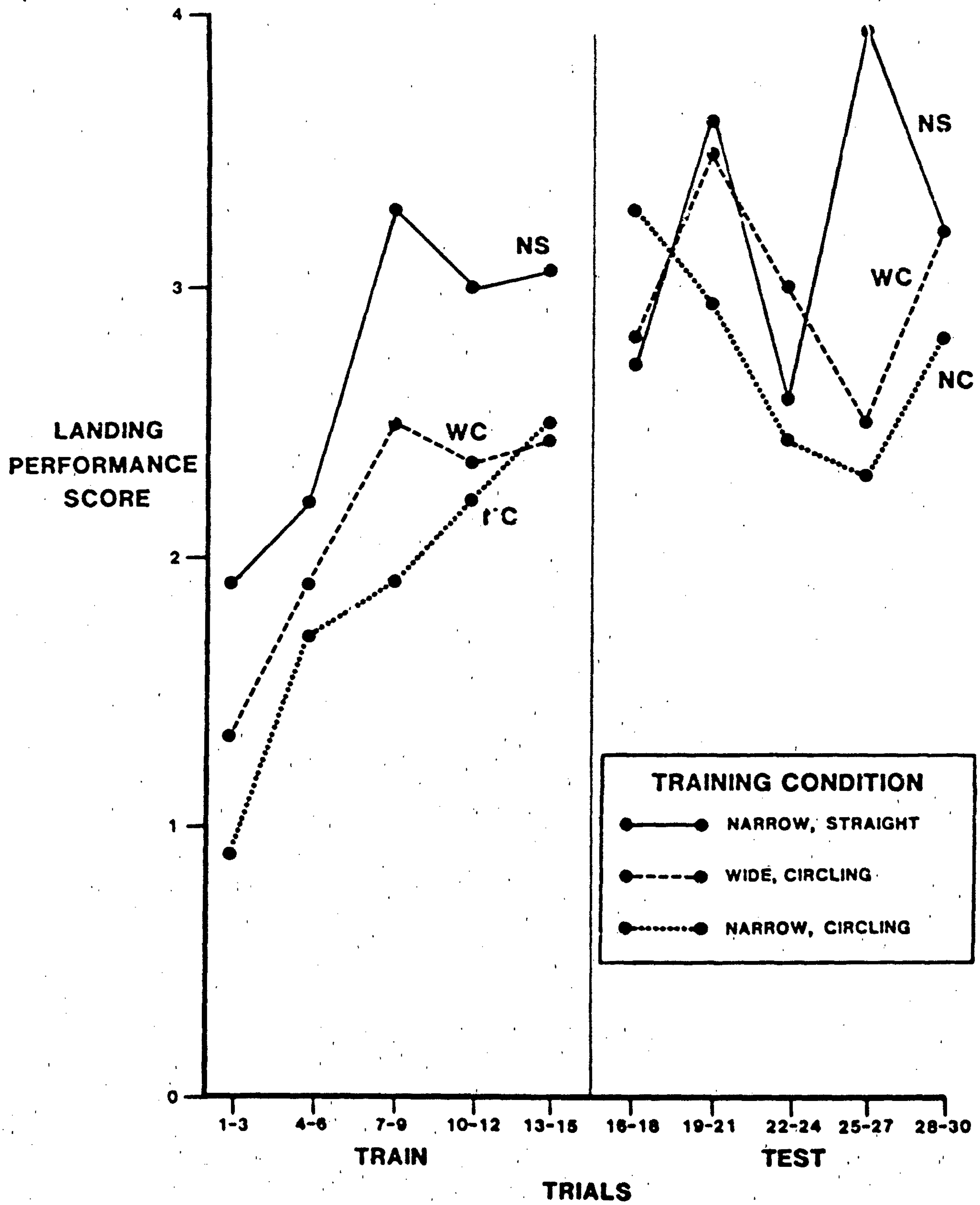

Figure 4. The Landing Performance Score for Blocks of Three Trials.

TABLE 6. PERCENTAGES OF LANDING OUTCOMES IN EACH OF FOUR CATEGORIES

Group	Outcome	Training Trials 1-15	Testing Trials 16-30
WC	Traps	26	48
	Waveoffs	41	7
	Bolters	26	32
	Ramp Strikes	7	13
NC	Traps	21	43
	Waveoffs	50	22
	Bolters	16	26
	Ramp Strikes	13	9
NS	Traps	38	51
	Waveoffs	23	14
	Bolters	29	14
	Ramp Strikes	10	21
TOTALS	Traps	28	47
	Waveoffs	38	14
	Bolters	24	27
	Ramp Strikes	10	12

FINAL APPROACH PERFORMANCE

LSO Grades

Each pass was evaluated by the LSO and assigned a numerical grade on a scale which was essentially a 3 for 1 expansion of the scale normally used by LSOs to grade every carrier approach, during both training and fleet operations. Because it was anticipated that most passes would be on the lower half of the scale, expansion of the scale was considered worthwhile to permit finer distinctions. Table 3 provided a comparison between the scale used here and the one normally used. It may be seen from the descriptions of the meaning of the numbers that LSO scores are subjective and based on each LSO's experiences and extensive training over the years. The LSO in this experiment did his best to maintain a consistent standard across the entire study, and to apply the same criteria that he would use in evaluating fleet pilots. Thus, if a pass was judged "average", it was average with respect to an experienced Naval aviator.

The LSO grades are shown in Figure 5. It can be seen that the results are similar to those obtained for the LPS. There is a clear separation between the groups during training, with Group NS again superior, and all groups improved substantially across the 15 trials. The ANOVA showed significant effects for training condition ($p<.01$) and for trials ($p<.001$). After transfer to the WC condition, however, these differences disappeared and there were no significant effects.

Time Within Combined Tolerances (TWCT)

During carrier approaches, pilots are taught to attend closely to three major dimensions of the task: control of glideslope, lineup and AOA. Accordingly, a composite measure was developed to reflect a pilot's ability to control simultaneously these three components of the task. A score was computed for each trial that indicates the percentage of time from ½ mile to the ramp during which the pilot was simultaneously within tolerances for glideslope, lineup and AOA error. Tolerances were defined in terms of acceptable deviations, i.e., deviations which, in the LSO's judgment, would be considered within safe limits and which normally would not require an LSO call to the pilot. Tolerance levels are summarized in Table 2.

Results for the TWCT score are presented in Figure 6. During training, an ANOVA again showed large differences between groups ($p<.005$) as well as a large learning effect ($p<.001$). In the testing phase, although Group NC appears somewhat lower than the other two groups, there were no statistically reliable differences.

Individual Components

The three components of the TWCT were also examined individually, to see whether the results were more or less consistent across them. Table 7 presents a comparison between the three components and the TWCT (complete ANOVA tables are in Appendix A). Averages for the three training groups are shown and the probability levels for all significant effects are presented along with the η^2 values for those effects (Eta squared represents the proportion of the total variability in the data that is accounted for by a particular effect). It may be seen that the three component scores present a remarkably consistent picture: during training, Group NS performed best and (except

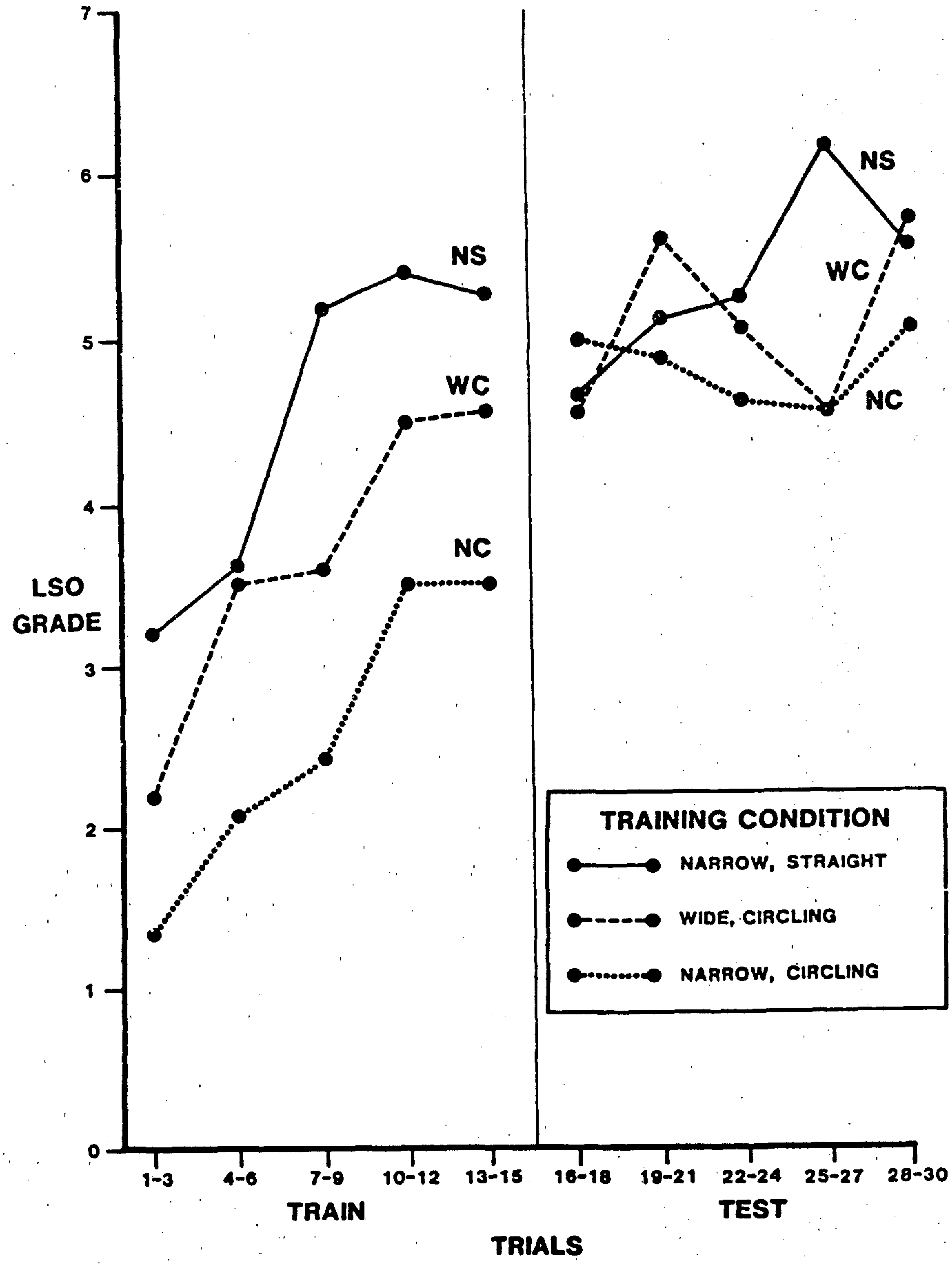

Figure 5. LSO Grade for Blocks of Three Trials.

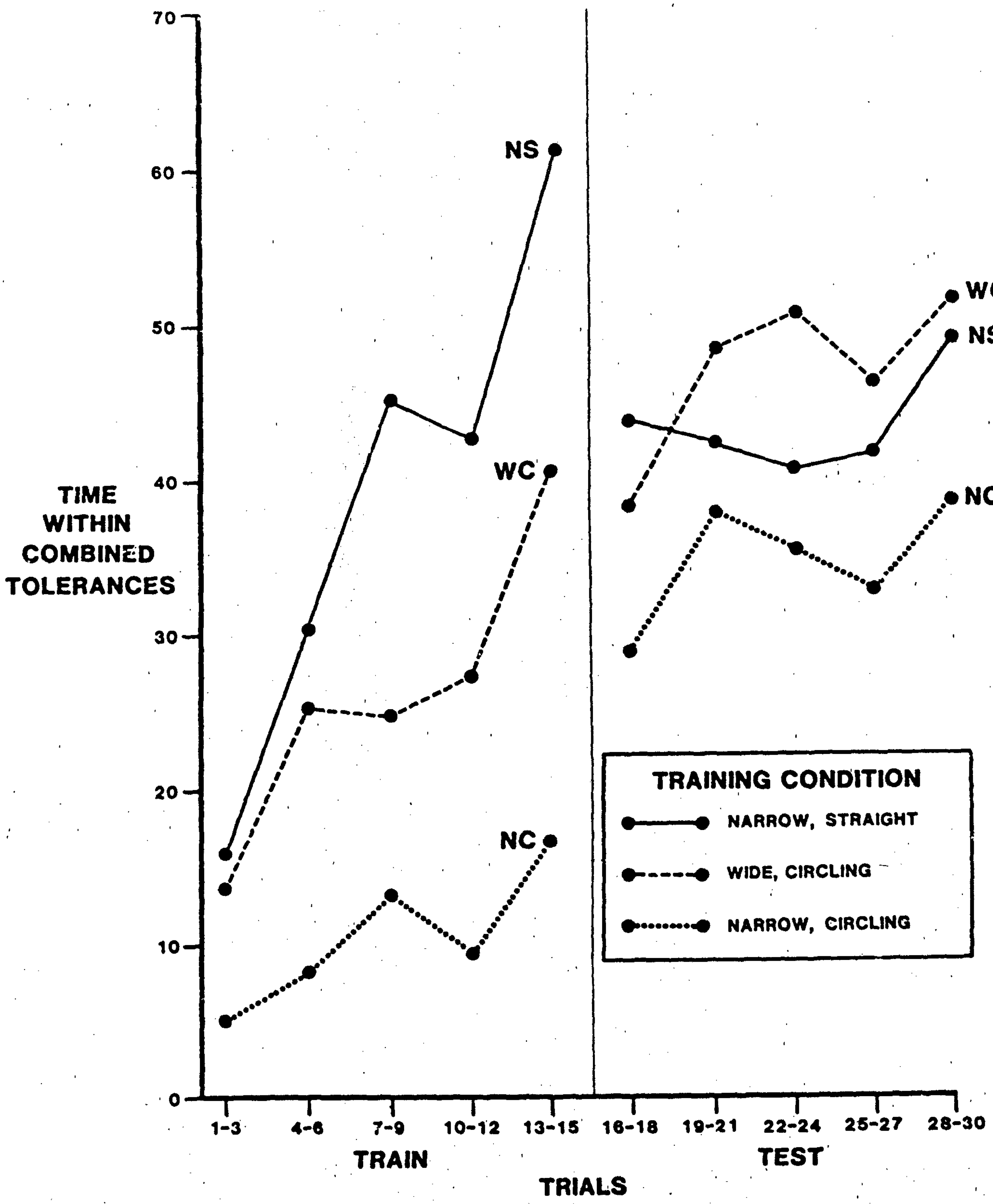

Figure 6. Time Within Combined Tolerances for Blocks of Three Trials.

TABLE 7. TRAINING GROUP AVERAGES, PROBABILITY LEVELS OF SIGNIFICANT EFFECTS, AND η^2 VALUES, FOR PERCENTAGE TIME WITHIN TOLERANCE SCORES (½ MILE TO RAMP).

	Glideslope	Lineup	Angle of Attack	Combined (TWCT)
<u>Training Trials (1-15)</u>				
Trng. Cond. Averages				
WC	49.76	61.30	71.44	26.34
NC	36.19	32.95	72.96	10.60
NS	59.17	69.65	83.09	39.33
Trng. Cond. Main Effects				
Probability Level	<.001	<.001	<.05	<.005
η^2	.12	.23	.05	.19
Trials Main Effects				
Probability Level	<.001	<.001	<.05	<.001
η^2	.17	.08	.07	.13
<u>Testing Trials (16-30)</u>				
Trng. Cond. Averages				
WC	70.67	73.90	81.76	46.40
NC	60.62	61.44	81.92	34.55
NS	67.61	71.31	83.17	43.42
Trng. Cond. Main Effects				
Probability Level	N.S.	N.S.	N.S.	N.S.
η^2	.03	.05	.00	.04
Trials Main Effects				
Probability Level	N.S.	N.S.	N.S.	N.S.
η^2	.06	.02	.03	.03

N.S. = Not significant (i.e., $p>.05$)

for AOA), Group NC performed poorest; during transfer there were no significant differences whatever. By comparing η^2 values during training, it is evident that differences between training conditions were greatest for lineup performance. In contrast, the greatest amount of improvement across trials occurred with glideslope control.

Performance Score Relationships

Relationships among the several measures discussed thus far were examined. Correlations between the LPS, the LSO grade, and the TWCT were computed and are presented in Table 8. Correlations are shown (a) for all trials (N=630), (b) for all trials except ramp strikes (N=564), and (c) for all trials except ramp strikes and waveoffs (N=398).

It should be noted that the correlations change in a predictable way across the three sets of data. Consider first the LPS-LSO correlations. Since both measures were assigned a value of 0 for ramp strikes, the removal of those trials should result in a lower correlation coefficient. Additionally, as waveoffs were always scored 1.0 for the LPS and usually were scored 1.0 by the LSO, a further reduction in the correlation should result upon elimination of these trials.

For the TWCT-LPS and the TWCT-LSO correlations the situation is different. On those trials resulting in a ramp strike, the pilot typically flew a reasonably good approach until very near the ship (otherwise he would have been waved off). When he did make a "fatal" mistake, it was too late for the LSO to do anything except watch. Therefore, while the LPS or the LSO grades were both 0 for these trials, the TWCT would be expected to be relatively high but variable across trials. Therefore, elimination of ramp strikes would be expected to increase these correlations. Waveoff trials are another matter. Here, approaches typically had a poor start and remained poor throughout the flight; hence, TWCT scores were uniformly low. Removal of those trials would therefore tend to decrease the correlations of TWCT with either LPS or LSO grades.

Regardless of which set of data is considered, the principal findings shown in Table 8 are consistent. Both objective summary measures considered here (LPS and TWCT) correlate quite highly with the more subjective LSO grades which reflect the real-world measure of performance used in the training and operational environments of the fleet. Furthermore, the correlation between the two objective scores is quite low, suggesting that these measures reflect different aspects of the tasks.

TABLE 8. TABLE OF INTERCORRELATIONS FOR LSO GRADE, LANDING PERFORMANCE SCORE (LPS), AND THE TIME WITHIN COMBINED TOLERANCES (TWCT)

(A) All trials (N=630)

	LSO	LPS	TWCT
LSO	1.00	.74	.49
LPS		1.00	.27
TWCT			1.00

(B) Ramp strikes eliminated (N=564)

	LSO	LPS	TWCT
LSO	1.00	.67	.60
LPS		1.00	.32
TWCT			1.00

(C) Ramp strikes and waveoffs eliminated (N=398)

	LSO	LPS	TWCT
LSO	1.00	.47	.52
LPS		1.00	.18
TWCT			1.00

To explore further the relations among different objective measures of final approach and touchdown performance, and their ability to predict real-world performance scores, a stepwise linear regression analysis was performed. In this analysis the criterion measure was LSO grades and the predictor variables were the LPS and the three components of the TWCT: percent time within tolerances for glideslope (GS), lineup (LU) and angle of attack (AOA) from ½ mile to the ramp. This analysis was based on the 398 trials resulting in touchdown (bolter or wire trap).

Table 9 summarizes this regression analysis. Several points should be noted. First, the predictor variables are shown to have a low correlation with each other. Second, the addition of each of the predictor variables examined does improve the multiple R (from .47 for LPS alone to .66 for all four). Third, even though the final step improved the multiple correlation very slightly, each variable made a large, statistically significant contribution to the final prediction equation.

TABLE 9. RESULTS OF STEPWISE LINEAR REGRESSION ANALYSIS.

(A) Table of intercorrelations

	LSO	LPS	GS	LU	AOA
LSO	1.00	.47	.45	.31	.26
LPS		1.00	.13	.02	.06
GS			1.00	.23	.32
LU				1.00	.09
AOA					1.00

(B) Stepwise addition of variables to predict LSO grades

Step	Variable(s) Included	Multiple R
1	LPS	.47
2	LPS + GS	.61
3	LPS + GS + LU	.65
4	LPS + GS + LU + AOA	.66

(C) Full model regression summary

Variable	Mean Square	df	F	Significance
LPS	203.83	1	117.55	<.001
GS	98.08	1	56.55	<.001
LU	58.49	1	33.73	<.001
AOA	14.06	1	8.11	<.005
Error	1.73	393		

In summary, these analyses indicate that the measures described were appropriate to the carrier landing task. The relevance of the LSO grades stems from the fact that they were only a slight modification of a scoring system used by the Navy for many years. The other measures examined do not correlate highly with each other, which shows they are measuring different aspects of performance. But they all appear to reflect components of the task that are relevant, in the sense that they all contribute significantly to the prediction of LSO grades. Together they indicate that the LSO's evaluation of a pass is based partly on final touchdown performance and partly on the pilot's ability to fly within prescribed tolerances fo the separate dimensions of control of glideslope, lineup, and AOA. The relevance of these measures is further supported by the fact that they have all been shown to be similarly affected by the training conditions, and all have shown a similar learning effect across trials during the training phase of the experiment.

As a final point, it is worth noting the similarity between the correlations obtained in this simulator study and some that have been reported for actual carrier landing performance. Brictson, Burger and Gallagher (1972) present data obtained from 65 inexperienced F-4 pilots during day and night carrier qualification trials. Their correlations between the LPS and the LSO's grades (4-point scale) were .50 at night, .33 during the day, and .45 overall.

PERFORMANCE DURING THE TURN

Beginning at the 180-degree position, scores were collected at five discrete points around the turn, and at ¼-mile intervals during the final approach. Data representing distance from the carrier during the turn and altitude above sea level are presented in Tables 10 and 11 (Part A); Part B of these tables presents centerline and glideslope error scores for the final approach segment. The distance and centerline deviation scores are also shown graphically in Figures 7 and 8.

Considering first the training scores (Table 10 and Figure 7), the effect of the narrow FOV was to cause pilots in Group NC to turn more tightly, so that when they crossed the center of the wake (90-degree position), they were, on average, 547 feet closer to the carrier than were the Group WC pilots. Altitude scores show no consistent differences (for both means and standard deviations) between the two groups. During the final approach both groups flew left of centerline, with Group NC slightly farther to the left and substantially more variable. Group NS, in comparison, flew much closer to centerline. The major difference between groups for glideslope error is that Group NC was considerably more variable than the other groups.

During the testing phase (Table 11 and Figure 8), Group NC continued to make the tightest turns, and WC the widest. It is interesting to note that NC pilots were the least variable of the three groups. During the final approach, the three groups are very similar with respect to both centerline and glideslope scores.

The final stages of training were also compared with the initial stages of transfer, in a search for differences that might have been obscured when the 15-trial averages were considered. Table 12 presents averages for the last three training trials, and Table 13 summarizes the first three test trials. While most of the relationships are similar to those seen for the entire data set, there is one substantial difference. On trials 13-15, Group NC made a tighter turn than Group WC, as it did on average during all the acquisition trials. However, on the first three test trials, Group NC turned much more widely (increasing their distance from the carrier at the 90-degree position by 961 feet over the three previous trials). Thus, when first tested with the wide FOV, Group NC pilots turned more widely than Group WC, which reverses the relationship shown for the entire testing phase.

TABLE 10. TRIALS 1-15 (TRAINING PHASE). GROUND POSITION AND ALTITUDES (IN FEET) DURING TURN AND FINAL APPROACH. GROUP MEANS AND STANDARD DEVIATIONS.

(A) During turn: Radial distance from carrier and altitude above sea level.

	Group					
	WC		NC		NS	
Position	Mean	S.D.	Mean	S.D.	Mean	S.D.
180° Distance	6172	37	6154	40	-	-
Altitude	585	32	591	33	-	-
157.5° Dist.	6516	173	6456	167	-	-
Altitude	552	63	555	62	-	-
135° Distance	6586	441	6527	506	-	-
Altitude	489	69	486	57	-	-
112.5° Dist.	5954	733	5795	815	-	-
Altitude	432	61	434	54	-	-
90° Distance	4260	988	3713	1129	-	-
Altitude	339	59	322	62	-	-

(B) During final approach: Lineup (LU) deviation to L(-) or R(+) of centerline, and glideslope (GS) deviation below (-) or above (+) glideslope.

	Group					
	WC		NC		NS	
Range	Mean	S.D.	Mean	S.D.	Mean	S.D.
½ mile LU	-146	174	-212	230	- 36	113
GS	-8	33	+14	45	+ 13	35
¼ mile LU	-17	47	-35	97	0	50
GS	0	18	+5	43	+6	21
at ramp LU	-8	18	-9	62	-2	17
GS	+8	21	+21	52	+9	20

TABLE 11. TRIALS 16-30 (TESTING PHASE). GROUND POSITION AND ALTITUDES (IN FEET) DURING TURN AND FINAL APPROACH. GROUP MEANS AND STANDARD DEVIATIONS.

(A) During turn: Radial distance from carrier and altitude above sea level.

Group

Position	WC Mean	WC S.D.	NC Mean	NC S.D.	NS Mean	NS S.D.
180° Distance	6161	33	6146	30	6163	39
Altitude	582	26	588	28	572	35
157.5° Dist.	6520	155	6438	119	6462	163
Altitude	563	50	544	45	528	61
135° Distance	6721	422	6494	351	6558	423
Altitude	507	59	483	50	478	48
112.5° Dist.	6168	680	5844	577	59[illegible]	605
Altitude	451	53	424	49	432	43
90° Distance	4452	1055	4140	815	4288	840
Altitude	368	64	337	42	349	48

(B) During final approach: Lineup (LU) deviation to L(-) or R(+) of centerline, and glideslope (GS) deviation below (-) or above (+) glideslope.

Group

Range	WC Mean	WC S.D.	NC Mean	NC S.D.	NS Mean	NS S.D.
½ mile LU	-120	159	-179	162	-179	171
GS	+3	18	+5	21	+2	23
¼ mile LU	-11	49	+6	42	-5	36
GS	+1	11	+3	14	0	12
at ramp LU	-4	10	-1	17	-3	10
GS	+2	6	+3	8	+1	6

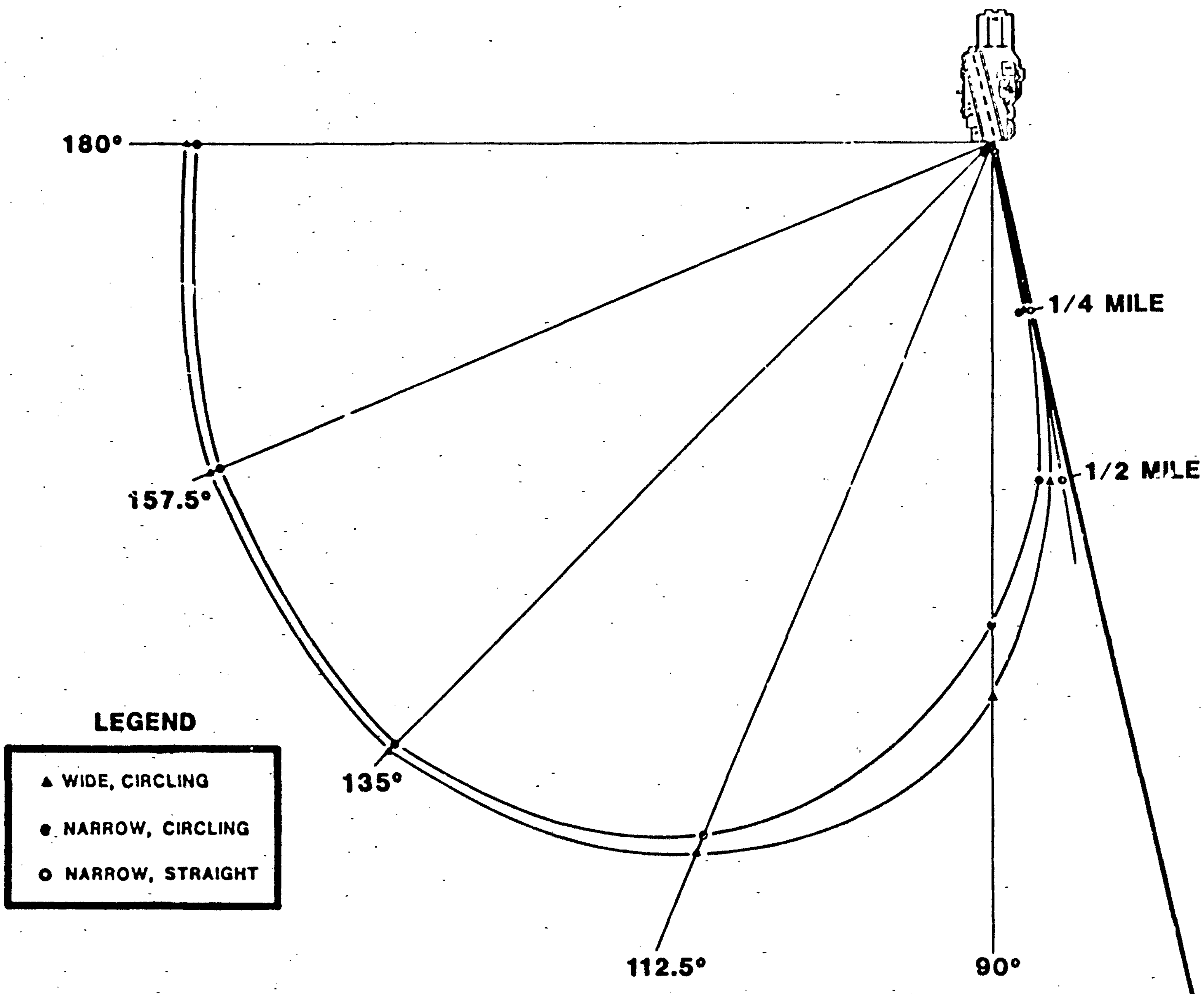

Figure 7. Positions During the Turn and Final Approach: Trials 1-15 (Training).

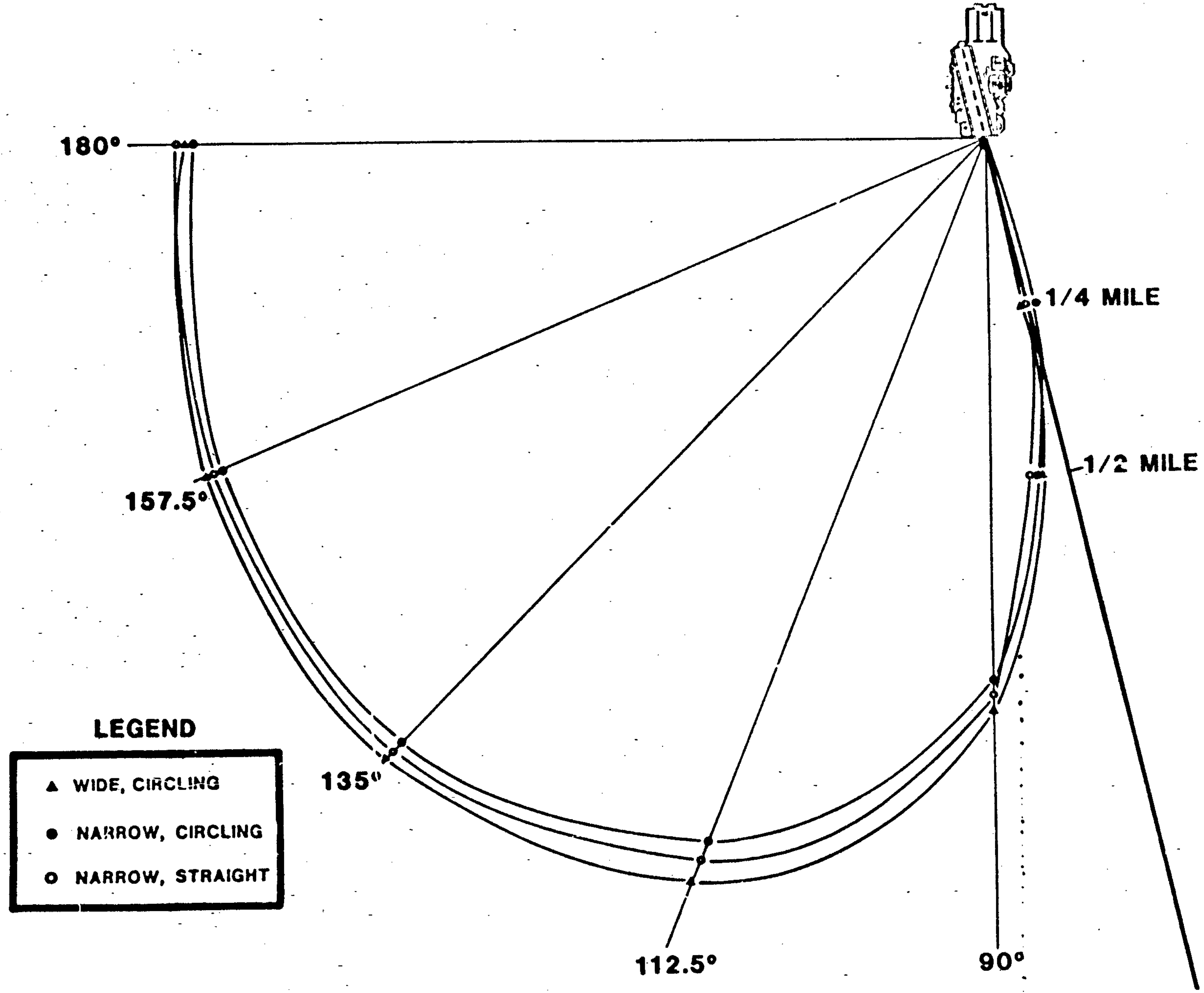

Figure 8. Positions During the Turn and Final Approach: Trials 16-30 (Testing).

TABLE 12. TRIALS 13-15. GROUND POSITION AND ALTITUDES (IN FEET) DURING TURN AND FINAL APPROACH. GROUP MEANS AND STANDARD DEVIATIONS.

(A) During turn: Radial distance from carrier and altitudes above sea level.

Group

Position	WC Mean	WC S.D.	NC Mean	NC S.D.	NS Mean	NS S.D.
180° Distance	6174	43	6155	37	-	-
Altitude	583	36	587	19	-	-
157.5° Dist.	6509	226	6456	136	-	-
Altitude	548	43	543	33	-	-
135° Distance	6528	482	6499	366	-	-
Altitude	482	56	477	39	-	-
112.5° Dist.	5871	729	5712	555	-	-
Altitude	439	42	424	46	-	-
90° Distance	4294	962	3636	728	-	-
Altitude	362	56	331	37	-	-

(B) During final approach: Lineup (LU) deviation to L(-) or R(+) of centerline, and glideslope (GS) deviation below (-) or above (+) glideslope.

Group

Range	WC Mean	WC S.D.	NC Mean	NC S.D.	NS Mean	NS S.D.
½ mile LU	-122	194	-256	163	-30	87
GS	-3	22	+27	30	+8	24
¼ mile LU	-3	48	+8	62	0	34
GS	+4	8	+3	18	+1	8
at ramp LU	-7	11	+8	26	-2	12
GS	+1	6	+6	13	+2	6

TABLE 13. TRIALS 16-18. GROUND POSITION AND ALTITUDES (IN FEET) DURING TURN AND FINAL APPROACH. GROUP MEANS AND STANDARD DEVIATIONS.

(A) During turn: Radial distance from carrier and altitudes above sea level.

Group

Position	WC Mean	WC S.D.	NC Mean	NC S.D.	NS Mean	NS S.D.
180° Distance	6172	35	6158	35	6181	36
Altitude	585	28	581	38	564	45
157.5° Dist.	6535	150	6490	147	6509	175
Altitude	560	51	537	55	512	70
135° Distance	6612	417	6639	435	6542	452
Altitude	509	64	467	59	464	57
112.5° Dist.	5910	690	6099	676	5812	656
Altitude	438	46	419	58	422	47
90° Distance	4040	1153	4597	965	4229	880
Altitude	341	66	352	38	338	49

(B) During final approach: Lineup (LU) deviation to L(-) or R(+) of centerline, and glideslope (GS) deviation below (-) or above (+) glideslope.

Group

Range	WC Mean	WC S.D.	NC Mean	NC S.D.	NS Mean	NS S.D.
½ mile LU	-185	169	-80	173	-126	156
GS	+6	19	+5	32	+5	27
¼ mile LU	-31	64	-2	45	-5	45
GS	+1	13	+4	15	+1	13
at ramp LU	-8	11	-16	17	-4	12
GS	+3	7	+6	8	+2	8

SECTION IV

DISCUSSION

Despite large differences during training, none of the three conditions of acquisition showed a clear superiority during the testing phase of the experiment. The Landing Performance Score, the measures of time within tolerance during the approach, and the LSO's grading of each pass all indicated that the NS group performed best during acquisition. Nevertheless, although pilots in this group received no training on the circling portion of the task, they were immediately able to perform the transfer task as well as the groups that received training on the full task. We believe this was because the most difficult skills to learn were those involving the control of glideslope and lineup during the final approach for which the NS condition presented the best conditions for practice. The initialization position for the NS pilots allowed them to get close to the centerline while they were still far from the ship, so that when they arrived within 3/4 to one mile of the carrier they had few gross errors of lineup to correct. This in turn permitted them more time to establish the correct rate of descent, thereby reducing glideslope errors. Our belief is that poorer performance on the final approach under the two circling approach conditions resulted because much time and effort was spent recovering from errors of lateral position when pilots rolled out of the turn. Clearly, approach control was poorest for the NC condition, which had the most restricted visual environment with which to negotiate the turn.

Further evidence for this interpretation comes from measures of the size of the significant effects. While differences between conditions of acquisition were reflected most by the measure of lineup control (23% of the variance), the largest changes seen across trials were in the glideslope score (17% of the variance). This suggests that while most of the learning during the experiment involved glideslope control the variable that dominated performance under the different training conditions was alignment with the landing deck at the start of the final approach. If fewer errors of lineup had to be corrected along the glidepath, better glideslope and AOA control were then possible. Better landings resulted, which were reflected by the higher LPS and by the LSO grades.

Support for this position can be seen in the measurements of the position of the aircraft during the turn. During acquisition the NC group had a tendency to make tighter turns than the WC group; this trend continued during the testing phase of the experiment. The tighter turn could have been simply a consequence of greater reliance on instruments, or it may have been made in order to obtain a visual image of the carrier earlier than would otherwise have been possible. In either case problems encountered in having less time on final approach to be correctly aligned with the carrier could have depressed this group's final approach performance.

A last point to note from the turn data is that, when pilots in the NC group were switched to the wide FOV test condition, they initially made much wider turns than before. They were almost 1000 feet farther from the carrier at the 90^{o} radial on the first three transfer trials than during the last three acquisition trials. This difference was not maintained, as their average distance at this position across Trials 16-30 was less than that of the WC group. This suggests that when first presented the wide FOV image, NC pilots may have initially depended almost exclusively on the visual display for the turn. They later may have reverted to a greater use of instruments, making the tighter turns that were more characteristic of their acquisition performance.

It should be emphasized that when the three groups were presented the same task, except for the tendency to make different turns just mentioned, their performance was virtually equivalent. This suggests that, for the carrier landing task, there are no clear training advantages of a wide angle visual display. In addition, there seems to be no reason to try to train the circling phase of carrier approaches using narrow angle display systems - indeed there is some evidence that inappropriate habits can be taught. The circling phase of a carrier approach does not appear difficult to learn and any training effort in a simulator is probably best spent on teaching glideslope and lineup control during the final approach.

Several factors should be considered when evaluating the results of the study. The subjects were proficient Air Force instructor pilots with a considerable amount of flying experience. Our reason for choosing them was that we wanted subjects who already knew how to fly well, but who knew nothing about the procedures and techniques of landing on carriers. Since only a limited amount of simulator time was available for this study, we did not want to spend any of that time teaching them more basic flying skills. One consequence of this decision was that some well-learned flying techniques interfered with the learning of this task. One such technique is flaring just prior to touchdown, which is not done when landing on aircraft carriers. Additionally, Air Force pilots do not normally fly constant AOA approaches and therefore do not use throttles as the primary means of controlling small changes in glideslope. Throughout the experiment many pilots continued to have difficulty adjusting to these new techniques and this tended to depress their approach and landing scores.

It should also be noted that these pilots were quite proficient at flying on instruments, as compared, for instance, with undergraduate Navy pilots entering the carrier landing portion of the flight syllabus. The result is that the performance of Group NC during training (and perhaps during transfer) may have been somewhat better than it would have been with less experienced pilots.

A final point to be considered is that while much learning obviously took place during the experiment, most pilots' performance at the end of the 2½ hours of simulator time had not approached operational levels of proficiency. Even though we believe the pilots improved as much as would be expected in 15 training flights, given the conditions of the experiment, more lengthy training sessions would probably have improved performance further. An actual training program involving the use of a simulator for teaching day carrier landings would undoubtedly involve considerably more simulated flights than was possible in this experiment. In view of the implications of this work for simulator design, it may be prudent to determine whether the principal results of this study will replicate under conditions of considerably greater training time and with less skilled pilots as subjects.

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APPENDIX A

ANALYSIS OF VARIANCE SUMMARY TABLES

These tables report the analyses of variance (ANOVAs) for a variety of measures (Type I design, Lindquist, 1953). Probability levels are indicated for those F-ratios significant at $p<.05$ or better; η^2 (the proportion of the total sum of squares for a given effect) is also shown for all significant effects.

TABLE A-1. ANOVA FOR THE LANDING PERFORMANCE SCORE.

(A) Trials 1-15 (Training Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	171.20	20				
Trng. Cond.	51.66	2	25.83	3.89	<.05	.05
Error (b)	119.54	18	6.64			
Within Ss	859.34	294				
Trials	94.68	14	6.76	2.39	<.005	.09
Trials x Cond.	55.56	28	1.98	0.68	N.S.	.05
Error (w)	709.10	252	2.81			
TOTAL	1,030.54	314				

(B) Trials 1-16 (Testing Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	133.27	20				
Trng. Cond.	12.51	2	6.26	0.93	N.S.	.01
Error (b)	120.76	18	6.71			
Within Ss	1,076.73	294				
Trials	49.39	14	3.53	0.95	N.S.	.04
Trials x Cond.	94.21	28	3.36	0.91	N.S.	.08
Error (w)	933.13	252	3.70			
TOTAL	1,210.00	314				

TABLE A-2. ANOVA FOR THE LSO GRADES.

(A) Trials 1-15 (Training Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	537.59	20				
Trng. Cond.	219.70	2	109.85	6.22	<0.01	.13
Error (b)	317.89	18	17.66			
Within Ss	1,214.40	294				
Trials	271.99	14	19.43	5.55	<0.001	.16
Trials x Cond.	59.44	28	2.12	0.61	N.S.	.03
Error (w)	882.97	252	3.50			
TOTAL	1,751.99	314				

(B) Trials 1-16 (Testing Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	313.13	20				
Trng. Cond.	15.47	2	7.74	0.47	N.S.	.01
Error (b)	297.66	18	16.54			
Within Ss	1,582.53	294				
Trials	64.71	14	4.62	0.83	N.S.	.03
Trials x Cond.	119.05	28	4.25	0.77	N.S.	.06
Error (w)	1,398.77	252	5.55			
TOTAL	1,895.66	314				

TABLE A-3. ANOVA FOR THE TIME WITHIN COMBINED TOLERANCES (TWCT)

(A) Trials 1-15 (Training Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	85,899.07	20				
Trng. Cond.	43,476.41	2	21,738.21	9.23	<0.005	.19
Error (b)	42,422.66	18	2,356.81			
Within Ss	148,246.38	294				
Trials	31,517.14	14	2,251.22	5.56	<0.001	.13
Trials x Cond.	14,550.49	28	519.66	1.28	N.S.	.06
Error (w)	102,178.75	252	405.47			
TOTAL	234,145.87	314				

(B) Trials 1-16 (Testing Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	69,752.82	20				
Trng. Cond.	7,975.44	2	3,987.72	1.16	N.S.	.04
Error (b)	61,777.38	18	3,432.08			
Within Ss	134,927.32	294				
Trials	7,045.86	14	503.28	1.10	N.S.	.03
Trls. x Cond.	12,112.56	28	432.59	0.94	N.S.	.06
Error (w)	115,768.90	252	459.40			
TOTAL	204,680.14	314				

TABLE A-4. ANOVA FOR GLIDESLOPE TIME WITHIN TOLERANCE.

(A) Trials 1-15 (Training Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	51,950.93	20				
Trng. Cond.	28,009.53	2	14,004.76	10.53	<0.001	.12
Error (b)	23,941.40	18	1,330.08			
Within Ss	187,356.27	294				
Trials	41,161.90	14	2,940.14	5.89	<0.001	.17
Trials x Cond.	20,358.12	28	727.08	1.46	N.S.	.09
Error (w)	125,836.25	252	499.35			
TOTAL	239,307.20	314				

(B) Trials 1-16 (Testing Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	41,056.08	20				
Trng. Cond.	5,577.65	2	2,788.83	1.41	N.S.	.03
Error (b)	35,478.43	18	1,971.02			
Within Ss	122,359.40	294				
Trials	9,531.37	14	680.81	1.68	N.S.	.06
Trials x Cond.	10,600.75	28	378.60	0.93	N.S.	.06
Error (w)	102,227.28	252	405.67			
TOTAL	163,415.48	314				

TABLE A-5. ANOVA FOR LINEUP TIME WITHIN TOLERANCE.

(A) Trials 1-15 (Training Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	130,810.36	20				
Trng. Cond.	77,726.80	2	38,863.40	13.18	<0.001	.23
Error (b)	53,083.56	18	2,949.09			
Within Ss	203,531.73	294				
Trials	26,482.92	14	1,891.64	3.12	<0.001	.08
Trials x Cond.	24,479.37	28	874.26	1.44	N.S.	.07
Error (w)	152,569.44	252	605.43			
TOTAL	334,342.09	314				

(B) Trials 1-16 (Testing Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	68,346.77	20				
Trng. Cond.	9,104.35	2	4,552.18	1.38	N.S.	.05
Error (b)	59,242.42	18	3,291.25			
Within Ss	115,105.40	294				
Trials	4,019.61	14	287.12	0.74	N.S.	.02
Trials x Cond.	13,802.07	28	492.93	1.28	N.S.	.08
Error (w)	97,283.72	252	386.05			
TOTAL	183,452.17	314				

TABLE A-6. ANOVA FOR ANGLE OF ATTACK TIME WITHIN TOLERANCE.

(A) Trials 1-15 (Training Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	26,579.78	20				
Trng. Cond.	8,426.37	2	4,213.19	4.18	<0.05	.05
Error (b)	18,153.41	18	1,008.52			
Within Ss	140,636.07	294				
Trials	12,456.01	14	889.72	1.93	<0.05	.07
Trials x Cond.	11,742.76	28	419.38	0.91	N.S.	.07
Error (w)	116,437.30	252	462.05			
TOTAL	167,215.85	314				

(B) Trials 16-30 (Testing Phase)

Source	Sum of Squares	df	Mean Square	F-ratio	p	η^2
Between Ss	34,610.49	20				
Trng. Cond.	143.11	2	71.56	0.04	N.S.	.00
Error (b)	34,467.38	18	1,914.85			
Within Ss	84,624.47	294				
Trials	4,166.59	14	297.61	1.04	N.S.	.03
Trials x Cond.	8,601.69	28	307.20	1.08	N.S.	.07
Error (w)	71,856.19	252	285.14			
TOTAL	119,234.96	314				

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